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Excited states of ^{19}N and ^{21}O

F. Naulin, C. Détraz, M. Roy-Stéphan, M. Bernas, J. de Boer (*),
D. Guillemaud, M. Langevin, F. Pougheon and P. Roussel

Institut de Physique Nucléaire, B.P. nº 1, 91406 Orsay, France

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Résumé. — Les réactions nucléaires (^{18}O, ^{19}N) et (^{18}O, ^{21}O) sur une cible de ^{18}O permettent d'observer des états excités à 1,12 et 1,59 MeV dans ^{19}N et à 1,35 et 3,00 MeV dans ^{21}O. Une valeur plus précise de la masse de ^{19}N, 15,856 $\pm$ 0,050 MeV, est obtenue.

Abstract. — (^{18}O, ^{19}N) and (^{18}O, ^{21}O) nuclear reactions on a ^{18}O target provide measurements of excited state energies at 1.12 and 1.59 MeV for ^{19}N and at 1.35 and 3.00 MeV for ^{21}O. The ^{19}N mass is remeasured as 15.856 $\pm$ 0.050 MeV.

For neutron-rich nitrogen and oxygen isotopes, ground state masses are known up to ^{19}N [1, 2] and ^{22}O [3]. Two-body nuclear reactions which measure the Q-value and in this way determine an unknown mass excess have vanishing cross sections for even more exotic isotopes. It seems nevertheless worthwhile to use them to study excited states of nuclei with known mass excesses. We have performed such measurements for ^{14}B and ^{18}N [4] and we report in this letter the first observation of excited states of ^{19}N and ^{21}O. Quantitative results of this type, far from the valley of β-stability, set stringent constraints on the predictions of nuclear models [5].

The complex-rearrangement reaction $^{18}O(^{18}O, ^{19}N)^{17}F$ and the three-neutron transfer reaction $^{18}O(^{18}O, ^{21}O)^{15}O$ were induced by a ^{18}O beam from the Orsay MP-Tandem on a self-supporting Al_2O_3 target, 72 $\mu g.cm^{-2}$ thick and 90 % enriched in ^{18}O. The nuclei emitted were analysed by a 180° magnetic spectrometer, within a 4° to 8° angular range in the horizontal plane and a 4.8 msr. solid angle. They were detected in the focal area of the magnet by a system consisting of two resistive-wire proportional counters and an ionization chamber with a split anode, providing two energy-loss and one residual-energy measurements, with 2 % and 1.5 % resolution, respectively. This system allows off-line kinematical correction, through ray tracing, and provides redundant identification of the nuclei detected [4, 6]. The energy spectra of ^{19}N and ^{21}O are presented in figures 1 and 2.

(*) Permanent address : Sektion Physik, University of Munich, Germany.

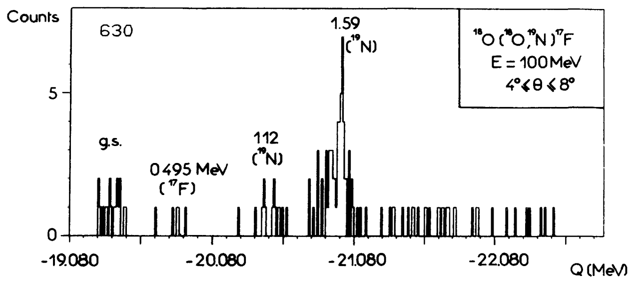


Fig. 1. — Energy spectrum of the ^{19}N nuclei emitted in the ^{18}O + ^{18}O reaction. The Q-value calibration is deduced from the observation of known transitions of nuclei of neighbouring A and Z values. The ground state cross section is about 0.5 μb.sr^{-1}.

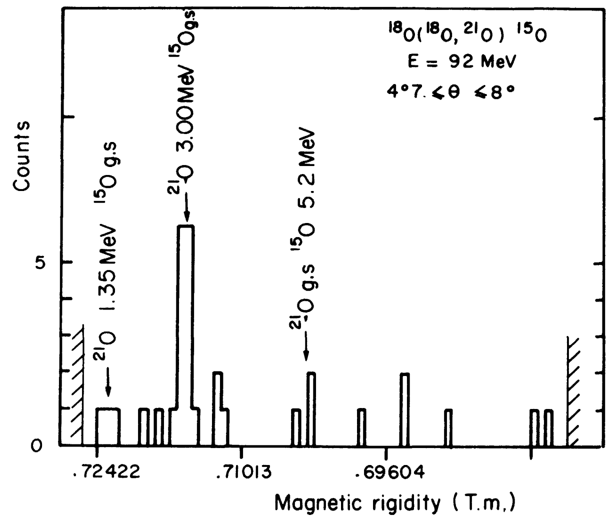
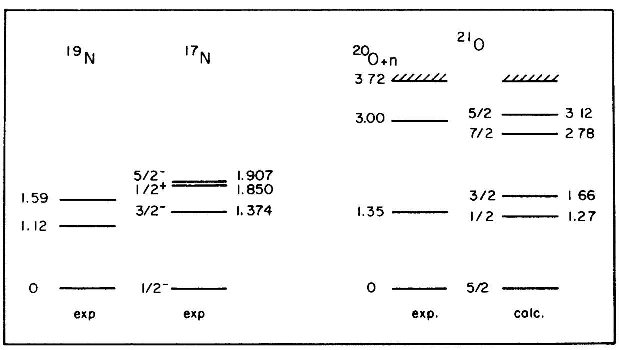


Fig. 2. — Spectrum of the position of ^{21}O nuclei, produced in the ^{18}O + ^{18}O reaction, along the focal plane of the spectrometer. The abscissa is the magnetic rigidity ($B\rho$ in tesla meter) of the observed ^{21}O nucleus. The experimental resolution is about 7 × 10^{-4} tesla meter, but the experimental peaks, labelled by the excitation energies of ^{21}O and ^{15}O, are Doppler-broadened for excited states of ^{21}O (the corresponding width is about 0.2 MeV per MeV of γ-decay energy). The six events of lower $B\rho$ can be assigned to various combinations of excited states of ^{21}O and ^{15}O. One count corresponds to a cross section of 7 nb.sr^{-1}.C.M.

The reasons why we chose to detect the exotic nucleus, for instance ^{21}O rather than ^{15}O, from the ^{18}O + ^{18}O two-body reaction are vividly illustrated by a comparison of the ^{21}O spectrum (Fig. 2) and the ^{15}O energy spectrum obtained in a previous measurement of the ^{21}O mass [7]. Because it corresponds to the less negative Q-value, ^{21}O from an ^{18}O target appears at higher kinematical energy than from the ^{16}O and ^{27}Al contaminants. Quite generally [4], in a two-body reaction the detected neutron-rich nucleus has an energy spectrum free of contaminants. There are however two drawbacks. First, one can observe as ^{21}O nuclei in the detectors only those formed in a particle-bound state, thus limiting the observable range of excited states. Second, because of their in-flight γ-decay, the bound states appear Doppler-broadened in the energy spectrum, as seen in figures 1 and 2. The beam energy had to be chosen very carefully for the ^{21}O measurement since the magnetic rigidity of the ^{21}O(8$^+$) nuclei emitted is very close to that of the $^{18}O(8^+)$ elastically scattered beam. Actually, it was impossible to observe the ground ^{21}O state without saturating and possibly damaging the detectors. It was found that a 92 MeV incident energy offered a broad range of observable excitation energies for ^{21}O. In that case, the field of the magnetic spectrometer was set at such a value which would put the scattered beam slightly off the focal plane detectors. As a result no possible excited state of ^{21}O could be observed below 1.2 MeV.

The energy spectrum of figure 1 provides a remeasurement of the ^{19}N mass as 15.856 ± 0.050 MeV. This is in agreement with but more accurate than previous values of 15.810 ± 0.090 MeV [1] and 15.960 ± 0.150 MeV [2]. Two transitions are identified to ^{19}N excited states at (1.12 ± 0.04) MeV and (1.59 ± 0.04) MeV. They could not be observed in our previous study [1] of ^{19}N since these peaks then fell outside the detector range. According to the straightforward shell-model prediction, the ^{19}N ground state should have $J^\pi = 1/2^-$. The same J^π value is found [8] for ^{17}N with one neutron pair less in the sd-shell, which should not perturb too much the proton hole-state. One can speculate that indeed the ^{19}N spectrum might closely parallel the ^{17}N one. Then low-lying excited states would have $J^\pi = 3/2^-$ and $5/2^-$ with a weak-coupling $[2^+ \otimes (1\,p\frac{1}{2})^{-1}]$ configuration [8]. Since the 2^+ state lies lower in ^{20}O than in ^{18}O, the lower excitation energies of the observed ^{19}N states, as compared to the ^{17}N ones (Fig. 3*a*), would find a natural explanation.



a) *b*)

Fig. 3. — Comparison of : *a*) the experimental level schemes of ^{17}N and ^{19}N ; *b*) the experimental level scheme of ^{21}O and the shell-model prediction of reference [9].

Two excited states of ^{21}O at 1.35 and 3.00 MeV are deduced from the energy spectrum of figure 2, within the energy range available, i.e. between 1.2 MeV due to the counter cut-off discussed above, and 3.72 MeV, the neutron binding-energy of ^{21}O. This result is compared (Fig. 3*b*) to a shell-model calculation [9] of the ^{21}O energy spectrum. If the experimental peaks of figure 2 correspond to single ^{21}O levels, the uncertainty of the measured excitation energy is $\pm$ 150 keV. However, the low statistics, the finite energy resolution of the detecting system, and the Doppler-broadening due to in-flight γ-decay of excited ^{21}O nuclei do not preclude the occurrence of more than one level within each experimental peak. In fact, since the shell-model calculations agree rather well with the spectra of light neutron-rich sd-shell nuclei, as noted [10] in the case of ^{25}Ne, our observation of two excited states of ^{21}O instead of the predicted four in the energy range covered by this experiment might be due to the occurrence of closely lying doublets.

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